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Abstract:

This report summarizes the projects I participated in this summer while working under the supervision of Dr. Elena Aprile as part of the Xenon10 collaboration stationed at the Gran Sasso National Laboratory. The report concentrates specifically on computer analysis of simulated cs-137 radiation in the xenon detector.

The Science of Dark matter

The goal of the Xenon 10 experiment is to detect dark matter. Dark matter is defined to be the matter which comprises the non-visible mass in the universe. To date, it is generally believed that the universe is 73% dark energy, 23% non-baryonic dark matter and 4% baryons that form the ordinary matter we know. Super symmetry hypothesizes that the dark matter is in the form of weakly interacting massive particles or WIMPS around 100 GeV in mass and unaffected by electromagnetic forces. This dark matter has been used to explain various cosmological observations.

The first person to postulate dark matter was Fritz Zwicky of Caltech in 1933. He used the motion of galaxies on the periphery of the Coma cluster to approximate the mass of the system. These calculations, however, described 400 times more mass than was observable from the brightness of the cluster. Zwicky concluded that there must be anther type of non-visible or dark matter which holds together the system.

A second set of evidence necessitating the existence of dark matter comes from the rotational curves of stars in spiral galaxies. In 1975 Kent Ford and Vera Rubin announced that they observed stars on the edge of these spiral galaxies which would travel at approximately identical speed as those closer to the center. Given the visible mass in these galaxies, one would expect the speed to drop off with radius. Therefore, they inferred that there was a uniform dark mass density in the form of a dark galactic halo far beyond the visible bulge of the galaxy.

The comic microwave background as well as gravitational lensing also point towards a model of the universe which includes dark matter. The cosmic microwave background is the radiation resulting from the big bang and it fills out universe. Once the hot plasma of baryons, photons and electrons from the big bang cooled to 3,000K protons and electrons were able to combine. The photons left over remained in the form of radiation. This radiation cooled to its present temperature of just under 3K moving into the microwave spectrum. Using a map of the cosmic background of the universe anisotropies are detected which scientists believe result from dark matter. Gravitational lensing is defined as the bending of light by the gravitational force of large bodies. The bending of light from distant galaxies has led to postulations describing various mass density gradients throughout space.

The XENON Experiment

The XENON project plans to use the scintillation and ionization produced by radiation in liquid xenon to detect WIMPs. Given enough time a WIMP will move into the detector and collide with a xenon atom. This collision will lead to a scintillation and ionization signal from resulting nuclear recoil (the s1 and s2 signals respectively). From these detected by arrays of photomultipliers (PMTs) operating in the liquid or its cold vapor, an image can be created which will be able to indicate a WIMP detection. The difficulty with this method is that many other natural sources are radioactive and therefore cause signals in the detector too. Through understanding the marks of these sources, the WIMP signal can be differentiated from background.

REU Work

The beginning of my time at Gran Sasso I spent reading articles on dark matter and XENON to build knowledge base about the project. Speaking with members of the collaboration both in the lab as well as at home and at social events on weekends proved to be an invaluable resource. Each member had a specific area of interest and expertise which they were excited to discuss. As well a series of lectures by visiting Prof. Hitachi on the interactions of particles in noble liquids was very informative. The subject matter of his speeches was obviously pertinent to my understanding of xenon but as well, I enjoyed his wider subject matter which covered all noble liquids.

Following that phase of my summer, a more hands on approach was taken. Time was spent touring the underground lab to see the detector at work. As well, circuits were built under the supervision of Angel Manzur for temperature regulation inside the shield. The moving of the detector from its old trailer to the new one so that it could be under a new lead shield provided another opportunity to be underground. The trailer was set up and cleaned to remove dust which could lead to impurities in the experiment.

The third and final phase of my work at the Gran Sasso Lab involved learning and programming in ROOT. Nevis tutorials on ROOT were first worked through to learn histogram construction and other basic tasks. Then under the supervision of Guillaume Plante, the Columbia Physics graduate student, my work moved to simulating events and analyzing various data sets created by Geant4. Computer simulations of Geant4 are crucial for the development of a project like XENON because they allow scientists to build up a better understanding of how the detector responds to various types of radiation and the signals it records. The many variables of the system can easily be altered without the disassembly and reassembly of a physical experiment.

The first simulation I worked with was of a positron source (PET position emission tomography). PET images require a beta plus emitter. Positrons and electrons are released. When they meet and annihilate they produce two oppositely traveling 511keV gamma rays to conserve energy and momentum. A ring detector is in the vicinity of the radiation source and it records gamma ray hits. Work with this simulation allowed me to build familiarity with the ROOT language as well as build an understanding of the geometry and signals collected from a detector similar to XENON. The angular distribution of the photons scattered once, and the energy distribution for all photons are examples of some of the graphs made. As well, work with loops allowed summations of data subsets representing specific properties.

The second simulation involved a Cesium 137 source placed near the detector. Cesium emits 662 keV gamma rays when it decays which interact in liquid xenon mainly via Compton scattering, with a smaller probability of photoabsorption. The ionization and scintillation produced by a Compton electron or a photeoelectron from the 662 keV interactions, lead to the S1 or S2 signals. The detector has a Teflon layer on the sides. The Teflon is able to reflect the VUV photons of the xenon scintillation, so it increases the percentage which stay in the chamber and reach the PMTs. For the simulations run the reflectivity was set to 95%. The absorption length of liquid xenon works against this property by ‘eating up’ the photons as they travel through the liquid. The simulation was run for 5 different xenon absorption lengths (50, 75, 100, 125 and 150cm). For each parameter Geant4 simulated 169,000 events. The simulations were also run 8 times per reflectivity and then merged into one large data file.

A separate histogram was formed for the total number of PMT hits using the data from each absorption length. A Gaussian was fit to the right peaks on each gap which represented the events which deposited all their energy in the detector. As expected the maximum energies deposited in the detector increased with absorption length~~.~~ (compare fig. 1 to fig.2).

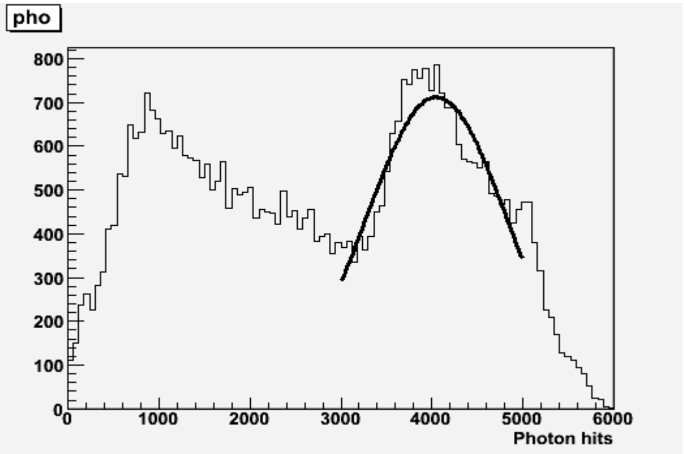


fig. 1.

Simulated Cs-137 662 keV gamma rays energy spectrum as detected via liquid xenon scintillation. Run with 75 cm absorption length

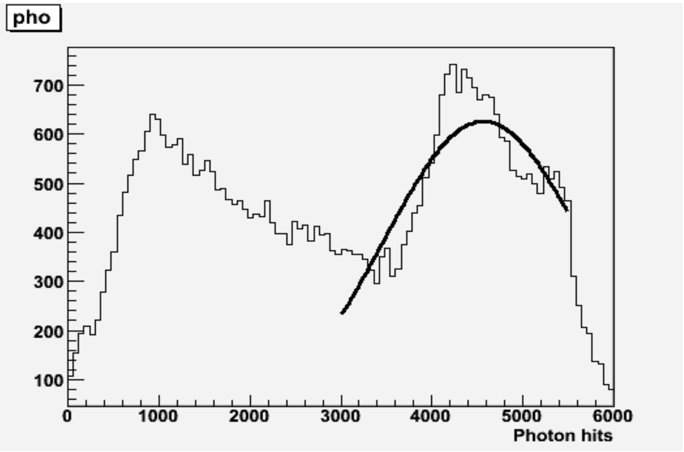


fig. 2
Simulated Cs-137 662 keV gamma rays energy spectrum as detected via liquid xenon scintillation. Run with 100 cm absorption length.

A similar graph was made for the PET simulation. It had just one peak at the maximum energy possible to deposit~~.~~ It was expected that a similar shape would result this time however two peaked graphs were created. This was a result of the geometry of the detector. The detector has gas portion on the top and then liquid below. Because of the change in medium there is internal reflection on the top below the PMTs which increases the amount of photons which are reflected back to the bottom array of PMTs.

The effects of the geometry of the detector were explored by making a cut and only graphing the total number of hits for the bottom PMTs with energies above 662 keV (the energy of the incoming gamma rays). Then a different graph for the total number of hits resulting from 662 keV events originating in the top of the detector was created. First it was necessary to understand the coordinate system of the detector (fig. 3). The top of the liquid in the detector is at 0 while the bottom of the detector where the PMTs array is, 120cm. We see clearly by comparing figure 4 to figure 5 that events in the bottom of the detector have more PMT hits.

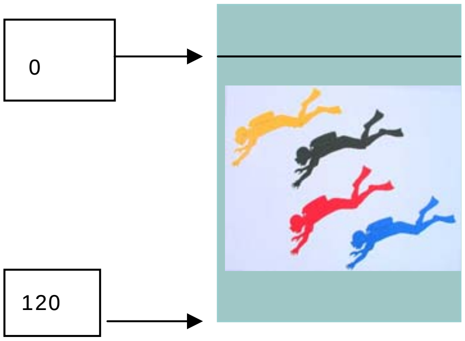


fig. 3

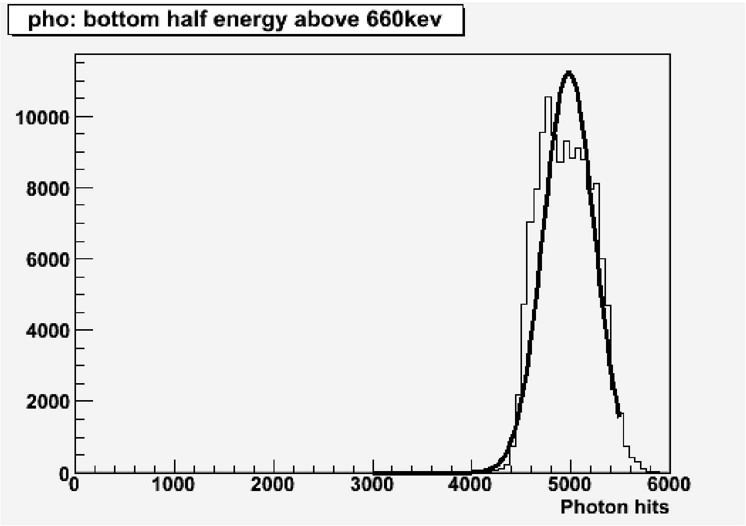


fig. 4

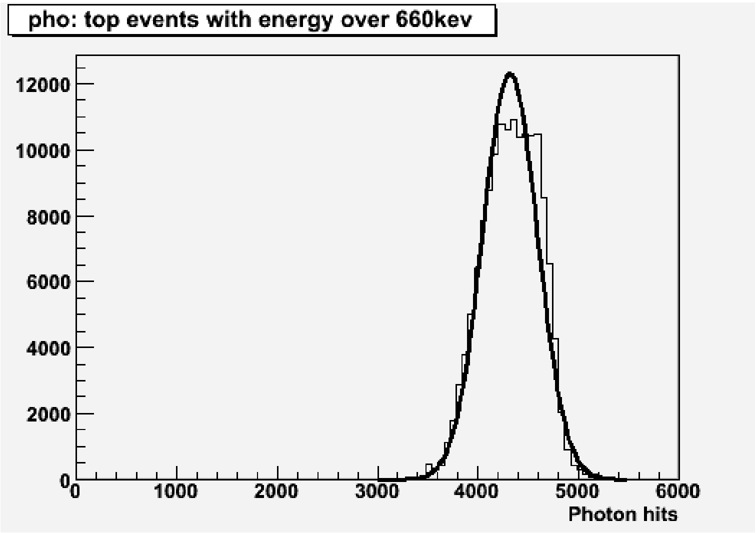
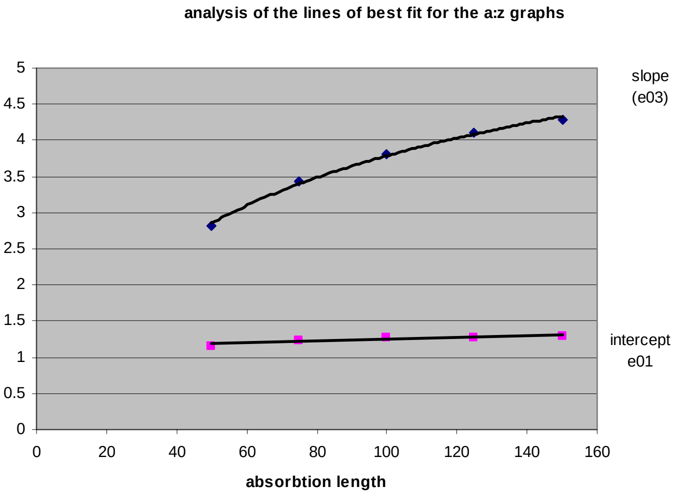


fig. 5

Graphing total number of PMT hits vs. the position for each of the 5 simulations we see that there is a linear fit for the data set (fig 6). Interestingly there is not an exact linear relationship between the slopes of the different simulations (as seen in the graph 1). The larger the negative number the larger the number of PMT hits at shorter distances in the detector. Even if not linear I would have predicted a linear increase in the slope with reflectivity (because more photons are trapped in the detector). However I now believe that there are regions in the detector which have lower resolution ability than others because of their relative distance from the PMTs combined with the reflectivity.



Graph 1.

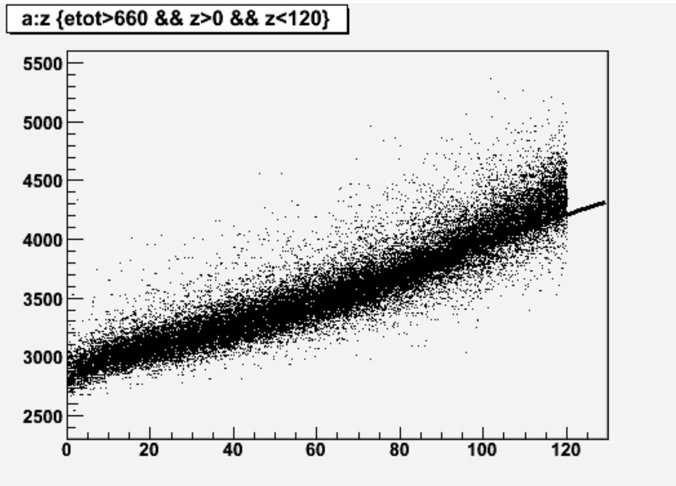


fig. 6 PMT hits vs. detector position

Conclusion

In conclusion my work with XENON has deepened my knowledge of astrophysics and given me insight into the research process. As well using ROOT as an analysis tool I have developed an understanding of the problems effecting resolution in the detector and specifically its variation with position.

Acknowledgements

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